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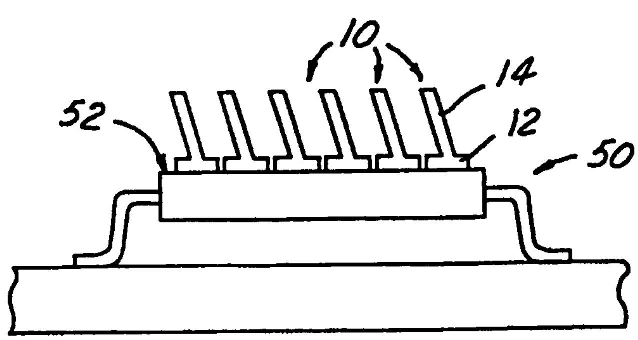
(54) Title: SHAPE MEMORY ALLOY HEAT SINK



(57) Abstract

There is disclosed herein a heat sink composed of a one-way or two-way shape memory alloy (SMA) having a predetermined martensite/austenite transformation temperature. The heat sink (10) comprises a stationary base portion (12) capable of being thermally attached to an electronic device (50), and at least one deflectable fin portion (14) contiguous with and extending from the base portion (12). Each fin portion (14) exhibits or is bent into a first shape when the heat sink (10) is below the transformation temperature. When the heat sink (10) is at or above the transformation temperature, the SMA material converts thermal energy from the device (50) into mechanical deformation energy such that each fin portion (14) self-deflects into a second shape.

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SHAPE MEMORY ALLOY HEAT SINK

The present invention relates generally to heat sinks for electronic devices. More particularly, the present invention relates to heat sinks for electronic devices utilizing a shape memory alloy.

It is well known in the art of electronics manufacturing that many electronic devices produce large amounts of unwanted heat during operation. Many approaches have been proposed for helping to remove some of this unwanted heat, such as using fans to blow air across the devices, placing heat pipes (e.g., thermal vias) in thermal contact with the devices, and, most typically, attaching metallic heat sinks to the devices. Such heat sinks are usually made of copper or aluminum, and are typically finned in order to provide a greater surface area-to-volume ratio to improve convection of heat away from the heat sink.

Copper and aluminium (and alloys containing mostly copper and/or aluminum) are typical choices for heat sink materials due to their superior thermal conductivity (394 and 222 W/m•°C for copper and aluminum, respectively). Copper is a better conductor than aluminum, but it is also more expensive. The only other common materials having a thermal conductivity approaching that of copper and aluminum are lithium (301 W/m•°C), gold (310 W/m•°C), silver (407 W/m•°C), and diamond (542 W/m•°C). However, these are poor heat sink material candidates because lithium has such a low melting point (179 °C) and is not very durable, while gold, silver, and diamond are prohibitively expensive.

For most applications, copper and/or aluminum heat sinks are acceptable. However, as electronic devices and printed circuit boards become more and more miniaturized, and as devices work at higher speeds producing greater amounts of unwanted heat, it is becoming increasingly difficult to produce a heat sink out of copper or aluminum that is capable of dissipating enough heat while being small enough to fit on the smaller devices. It would therefore be

desirable to find some other material which could be used to make smaller heat sinks having high thermal dissipation characteristics.

The present invention provides a heat sink constructed of a one-way or two-way shape memory alloy (SMA) material having a predetermined martensite/austenite transformation temperature. The hat sink comprises a stationary base portion capable of being thermally attached to an electronic device, and at least one deflectable fin portion contiguous with and extending from the base portion. Each fin portion exhibits or is bent into a first shape when the heat sink is below the transformation temperature. When the heat sink is at or above the transformation temperature, the SMA material converts thermal energy from the electronic device into mechanical deformation energy such that each fin portion self-deflects into a second shape.

It is an advantage of the present invention that the conversion of thermal energy into mechanical deformation energy is so pronounced that heat sinks can be produced in a much smaller size when constructed of an SMA material as compared to conventional heat sink materials.

It is a further advantage that either one-way or two-way SMA materials may be utilised to construct heat sinks according to the present invention.

The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. 1 is an elevational view of one embodiment of a heat sink according to the present invention;

FIG. 2 is an elevational view of another embodiment of a heat sink according to the present invention;

FIGS. 3A-B are elevational views of a heat sink constructed of a two-way SMA according to the present invention for the cases of $T < T_t$ and $T \geq T_t$, respectively;

FIGS. 4A-D are cross-section views showing various configurations for attaching a heat sink to an electronic device according to the present invention;

FIG. 5A-C are elevational views of a heat sink constructed of a one-way SMA according to the present invention showing as-manufactured, bent, and remembered shapes, respectively;

FIG. 6A-D are elevational views of heat sinks constructed of a one-way SMA according to the present invention each showing a mechanically connected means for restoring; and

FIG. 7A-C are elevational views of heat sinks constructed of a one-way SMA according to the present invention each showing a not-mechanically-connected means for restoring.

Referring now to the drawings, FIG. 1 shows an array of heat sinks 10 attached to an outer surface 52 of an electronic device 50. Each heat sink 10 comprises a stationary base portion 12 capable of being thermally attached to an electronic device 50, and at least one deflectable fin portion 14 contiguous with and extending from the base portion 12. An alternative embodiment of this is shown in FIG. 2, where there is only one base portion 12 having a plurality of fin portions 14 extending therefrom.

The heat sink is composed of either a one-way or a two-way shape memory alloy (SMA) material. The most common types of SMAs are binary alloys of nickel and titanium, such as Nitinol, or ternary alloys of copper-zinc-aluminum or copper-aluminum-nickel. These materials undergo a phase transformation from martensite to austenite when the material is raised from a temperature T below its transformation temperature T_t to a temperature T at or above the transformation temperature T_t. An object made of an SMA can be plastically deformed relatively easily from a first "as manufactured" shape to second "bent" shape while at a temperature below T_t; then, when the object is heated to at

or above T_t, the object will self-deflect back to the first shape. If any other intervening object stands in the way of this self-deflection, the SMA object may exert great force against the other object in order to return to its original shape. This "remembering" of the original shape provides the basis for naming this phenomenon the "shape memory effect", and for naming these materials "shape memory" alloys. SMAs that exhibit this shape memory effect only upon heating above T_t are referred to as "one-way" SMAs, while those which also undergo a change in shape upon cooling to a temperature below T_t are called "two-way" SMAs.

Heretofore, SMAs have been used to construct force actuators, constrained recovery devices, and the like, taking advantage of the force, constriction, deflection, and/or interference provided or exhibited by an SMA element responding to heat. However, SMAs have heretofore not been used to construct heat sinks. This is because of the rather unremarkable thermal conductivity of SMA materials. For example, nickel-titanium SMAs have thermal conductivity (k) values of only 18 and 9 W/m•°C for its austenite and martensite phases, respectively. The copper-based SMAs are better, but no better than other readily usable materials. For example, the CuZnAl and CuAlNi SMAs have k values of only 120 and 30-43 W/m•°C, respectively, as compared to k values of 165 W/m•°C for beryllium, 168 W/m•°C for graphite, 157 W/m•°C for magnesium, 145 W/m•°C for molybdenum, 140 W/m•°C for die-cast zinc, and 130 W/m•°C for tungsten. Additionally, although SMA materials may be easily molded, they are generally difficult to machine, thus requiring the use of abrasive techniques to provide the smooth part surfaces that would be needed for thermally attaching an SMA element to a heat source. Furthermore, SMA materials are relatively expensive. Thus, it can be seen why SMA materials do not present themselves as good candidates for heat sink materials at first blush.

However, the very quality which makes SMAs a good material for constructing force actuators, constrained

recovery devices, and the like — i.e., the inherent shape memory effect — is in actuality a quality which makes SMAs a good heat sink material. This is because an SMA element must absorb a large amount of heat over a relatively short period of time at or about a precise temperature (T_t) in order for the SMA to produce the self-deflecting shape memory effect. This is because the SMA must absorb and convert a tremendous amount of thermal energy into mechanical energy to effect the martensite-to-austenite phase transformation and the concomitant shape transformation. Although the SMA element may not be a very remarkable conductor of heat away from a thermally attached heat source when the heat source/SMA element are below the SMA's transformation temperature T_t, when the heat source/SMA element approach T_t the SMA element acts as a dynamic heat sink which can wick away large amounts of heat from the heat source at a temperature around T_t.

SMAs may be alloyed such that the transformation temperature T_t can be predetermined. For example, for NiTi SMAs, T_t can be manipulated in this way so as to fall somewhere between -200 and 110 °C. Therefore, a heat sink can be constructed of a particular SMA alloy having a particular T_t which corresponds in some way to a critical operating temperature of an electronic device to which the heat sink may be attached, thus allowing the transformation temperature to be predetermined. For example, a given device may have a critical maximum operating temperature of 100 °C and it may be desired to have a heat sink that, in concert with the device, will not rise significantly above 85 °C; therefore, a certain nickel-titanium alloy can be selected for the heat sink which has a T_t of 85 °C.

When the heat sink 10 is composed of a two-way SMA, each fin portion 14 will exhibit a first shape when the heat sink 10 is below the SMAs transformation temperature T_t, as illustrated in FIG. 3A, and will exhibit a second shape when the heat sink 10 is at or above T_t, as shown in FIG. 3B. The creation of these first and second shapes are accomplished

by "training" the SMA element to "remember" these shapes. There are various methods for accomplishing this training, such as by overdeforming the element while in the martensitic phase, pseudoelastic cycling, constrained aging, as well as by other methods known to those skilled in the art to which the present invention pertains.

As the electronic device 50 to which the two-way SMA heat sink 10 is thermally connected heats up, the heat sink 10 will absorb heat from the device 50 by conduction and will dissipate heat to the surrounding atmosphere by convection. The heat sink 10 will continue to do this at a constant rate, albeit at a rate significantly lower than a conventional copper or aluminum heat sink of the same volume would. However, when the heat sink 10 approaches its T_t point, the heat sink will begin to absorb thermal energy from the device 50 at a much higher rate, converting this thermal energy into mechanical deformation energy whereby each fin portion 14 will deflect from its first shape to its second shape. (This of course assumes that enough thermal energy is output by the device 50 in order to complete this shape transformation. If not quite enough thermal energy is output, each fin portion 14 might deflect only a portion of the way between the first and second shapes.) The wicking away and transformation of heat is typically so great at this point that the device 50 is cooled to a temperature T below T_t, whereupon the heat sink 10 will likewise cool below this temperature, thereby causing each fin portion 14 to deflect from its second shape back to its first, whereupon the accelerated wicking and conversion may begin again. Thus, throughout this cyclical process, each fin portion 14 will be self-deflecting back and forth between its first and second shapes (and the entire heat sink 10 will be cycling back and forth between its martensite and austenite phases) as the heat sink absorbs heat and converts it into mechanical deformation. To maximize the heat dissipation effect, each fin portion should be unrestrained from any external, mechanically interfering element so that each fin

portion is free to cyclically deflect between its first and second shapes in response to temperature changes in the device 50.

FIGS. 3A-B show each heat sink base portion 12 attached to an outer surface 52 of an electronic device 50. However, the heat sink 10 may also be attached to an interior portion of the device, such as a substrate portion 54 or an electronic sub-component portion 56, as illustrated in FIGS. 4A-B. When the substrate portion 54 and/or electronic sub-component portion(s) 56 is/are encapsulated by a package portion 58 of the device 50, as illustrated in FIGS. 4C-D, each fin portion 14 may protrude through holes or slots in the package portion 58.

When the heat sink 10 is composed of a one-way SMA, each fin portion 14 has a first shape as originally manufactured, and is capable of being bent into a second "bent" shape while the heat sink 10 is at a temperature T below the SMA's transformation temperature T_t. Each fin portion 14 is further capable of deflecting back to its first shape from the second "bent" shape when the heat sink temperature T is at or above T_t. As with the two-way SMA heat sinks discussed above, the SMA material may be alloyed such that a predetermined T_t point is provided, which may correspond to a critical operating temperature of an electronic device 50 to which each heat sink base portion 12 may be attached.

FIG. 5A illustrates several heat sinks 10 each having its base portion 12 thermally attached to an electronic device 50. Here, each fin portion 14 exhibits a first, "as manufactured" shape. The fin portions 14 may then be bent while the heat sink/device are below the SMAs T_t point so as to assume a second, "bent" shape, as illustrated in FIG. 5B. As the device 50 produces heat, the heat sinks 10 will absorb and dissipate this heat via convection as would any conventional heat sink. However, when the device/heat sink temperature approaches T_t, the heat sink 10 will absorb vast amounts of heat from the device 50 and convert this

thermal energy into mechanical deformation energy, causing each fin portion 14 to self-deflect to its "remembered" first shape, as illustrated in FIG. 5C.

However, whereas a heat sink constructed of a two-way SMA (as discussed above) will automatically self-deflect back-and-forth between its first and second shapes as the heat sink temperature T oscillates between $T < T_t$ and $T \geq T_t$, respectively, a heat sink constructed of a one-way SMA will not automatically do so. In order for a one-way SMA heat sink to continue cycling between states of $T < T_t$ and $T \geq T_t$ wherein thermal energy continues to be converted into mechanical deformation energy as described above, some means for restoring 80 must be provided which is capable of restoring or resetting (i.e., bending) each fin portion 14 from its first, "original" shape into its second, "bent" shape. This means for restoring 80 can be a manually actuatable means such as the rack-and-pinion arrangement shown in FIGS. 6A-B, or an automatically actuatable means such as the normally-open electrical solenoid circuit shown in FIGS. 6C-D, or some equivalent of these. In either case, the means for restoring 80 would be mechanically connected to each fin portion 14 so that manual or automatic actuation of the means 80 would bend each fin portion 14 into its second shape, thus preparing each fin portion/heat sink for another energy conversion cycle. (As used herein, "manual" implies that some human intervention is required to actuate the means for restoring 80, whereas an "automatic" means 80 responds directly to the fin portions 14 exhibiting their first shapes and requires no direct human involvement in order to be actuated.)

It is also possible that the means for restoring 80 is not mechanically connected to any fin portion, as illustrated in FIGS. 7A-B. When this is the case, the heat sink 10 could include some form of indicator 90 capable of indicating a condition wherein each fin portion exhibits its first shape. This indication of condition could be accomplished by providing a distinctive color or marking on

only one side 16 of each fin portion and providing the first and second shapes such that the color or marking would only be detectable (to a sensor/indicator or to a human operator's eye, for example) when each fin portion 14 is deflected into its first position, as shown in FIG. 7A. Or, the indication of condition could be accomplished by some sort of proximity sensor/indicator positioned such that a signal or indication (e.g., a flashing light or buzzer) is generated when the sensor senses that each fin portion 14 is in its first shape, as shown in FIG. 7B. In either case, this indication of condition would be a signal to which a manual means for restoring 80 could respond by bending each fin portion back into its second shape.

Alternatively, the means for restoring 80 could be not mechanically connected to any fin portion 14 and, instead of the heat sink 10 including an indicator 90 to which a manual means for restoring 80 could respond, the heat sink 10 could include a sensor/indicator 95 to which an automatic means for restoring could respond, as illustrated in FIG. 7C. This sensor 95 would be capable of sensing and indicating a condition wherein each fin portion exhibits its first shape. Again, this sensor 95 could be a proximity or any other type of sensor capable of detecting and indicating the aforementioned condition. The indicating function would preferably be the issuance of a signal from the sensor, which would be used to trigger or actuate the means for restoring 80 so that each fin portion 14 would be bent into its second position. Once the means 80 has reset each fin portion into its second shape, the means could retract away from the fin(s) or remain to be pushed back by the fin(s) when the heat sink temperature T approaches T_t.

Regardless of whether a one-way or two-way SMA configuration is used, the absorption and conversion (and therefore dissipation) of thermal energy away from the electronic device 50 is so dramatic that the overall heat sink size can be made much smaller than would be the case

for conventional aluminum or copper heat sinks having substantially the same thermal dissipation effect.

Various other modifications to the present invention will, no doubt, occur to those skilled in the art to which the present invention pertains. For example, it should be readily apparent that first and second fin shapes and overall heat sink shapes other than those illustrated herein can be used. Also, when reference is made herein to the first and second shapes of the fin portions 14, it should be apparent that each entire heat sink 10 likewise has corresponding first and second shapes since each fin portion 14 is part of an overall heat sink 10.

CLAIMS

1. A heat sink composed of a two-way shape memory alloy having a predetermined martensite/austenite transformation temperature, comprising:

a stationary base portion (12) capable of being thermally attached to an electronic device (50), and

at least one deflectable fin portion (14) contiguous with and extending from said base portion (12),

wherein each fin portion (14) exhibits a first shape when said heat sink (10) is below said transformation temperature, and wherein each fin portion (14) exhibits a second shape when said heat sink (10) is at or above said transformation temperature.

2. A heat sink according to claim 1, wherein said base portion (12) is thermally attached to an electronic device (50).

3. A heat sink according to claim 2, wherein each fin portion (12) is free to deflect between said first and second shapes in response to temperature changes in said electronic device.

4. A heat sink according to claim 2, wherein said heat sink (10) may absorb thermal energy from said electronic device and convert said thermal energy to mechanical deformation energy so as to deflect from said first shape to said second shape when said heat sink heats from below said transformation temperature to at or above said transformation temperature.

5. A heat sink according to claim 2, wherein said heat sink (10) may dissipate heat from said electronic device so as to deflect from said second shape to said first shape when said heat sink (10) cools from at or above said

transformation temperature to below said transformation temperature.

6. A heat sink according to claim 2, wherein said base portion (12) is attached to an outer surface of said electronic device (50).

7. A heat sink according to claim 2, wherein said base portion (12) is attached to an interior portion of said electronic device (50).

8. A heat sink according to claim 2, wherein said predetermined transformation temperature of said heat sink (10) is chosen to be at a critical operating temperature of said electronic device.

9. A heat sink composed of a one-way shape memory alloy having a predetermined martensite/austenite transformation temperature, comprising:

a stationary base portion capable of being thermally attached to an electronic device, and

at least one deflectable fin portion contiguous with and extending from said base portion,

wherein each fin portion has a first shape as originally manufactured, and

wherein each fin portion is capable of being bent into a second shape while said heat sink is at a temperature below said transformation temperature,

each fin portion being further capable of deflecting back to said first shape from said second shape when said heat sink is at or above said transformation temperature.

10. A heat sink according to claim 9, wherein said predetermined transformation temperature of said heat sink is chosen to be at a critical operating temperature of said electronic device.

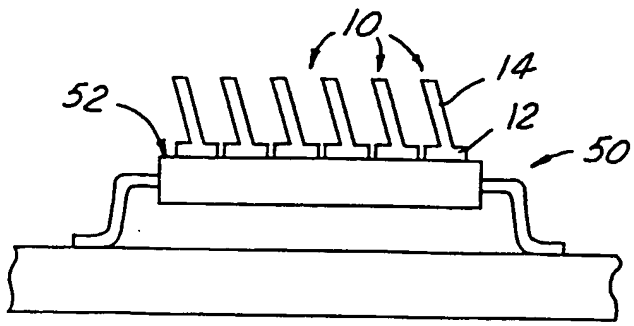

FIG. 1

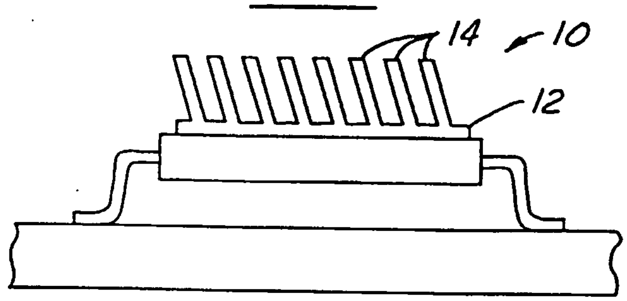

FIG. 2

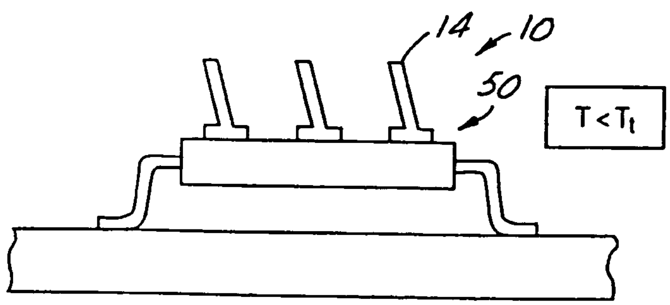

FIG. 3A

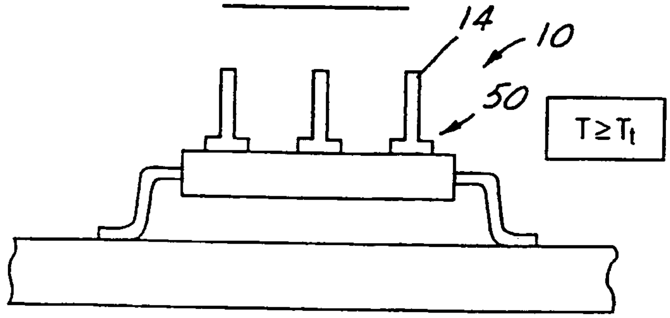

FIG. 3B

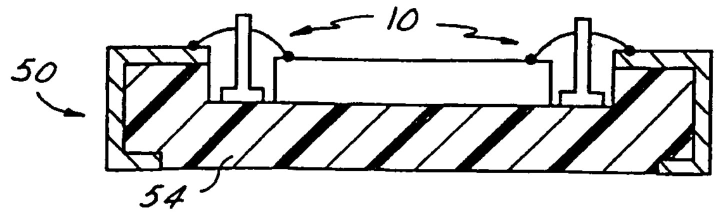

FIG. 4A

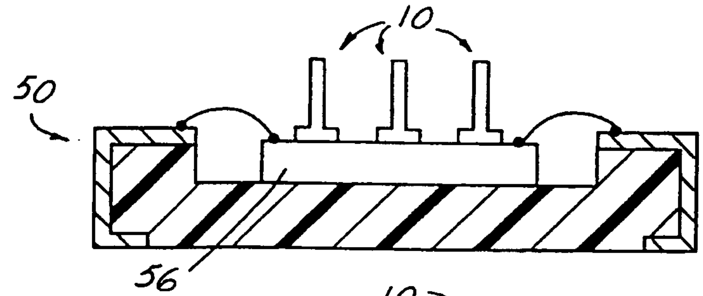

FIG. 4B

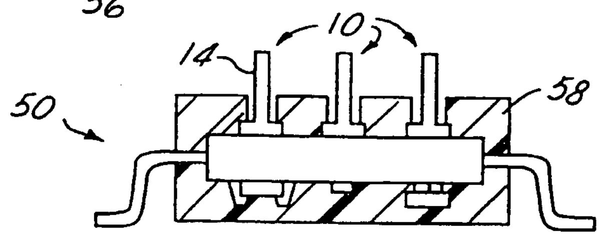

FIG. 4C

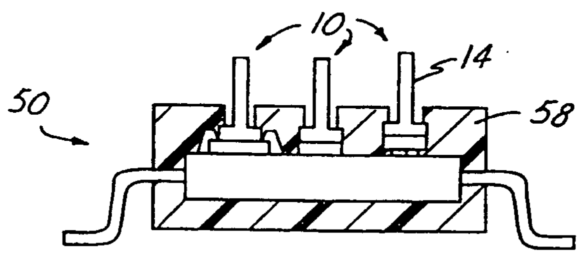

FIG. 4D

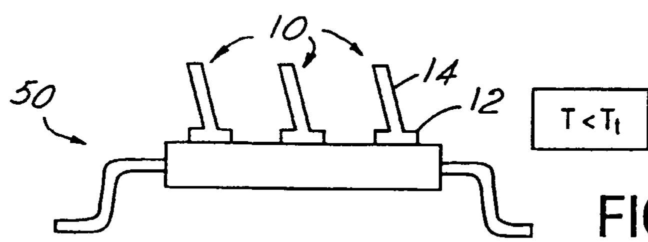

FIG. 5A

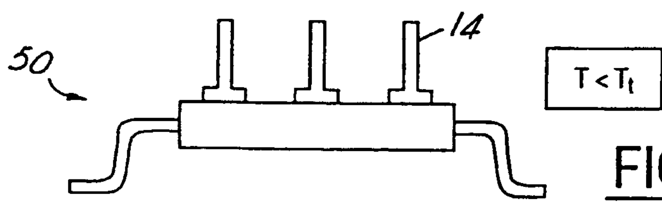

FIG. 5B

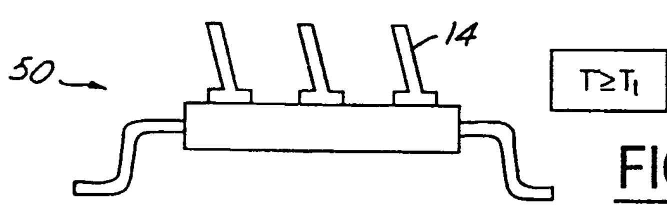

FIG. 5C

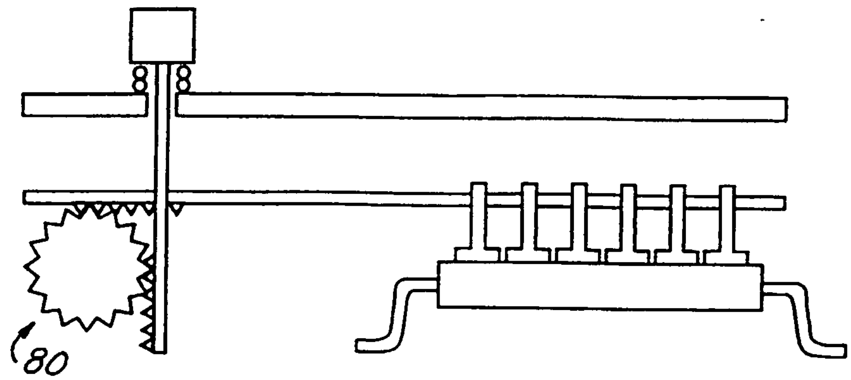

FIG.6A

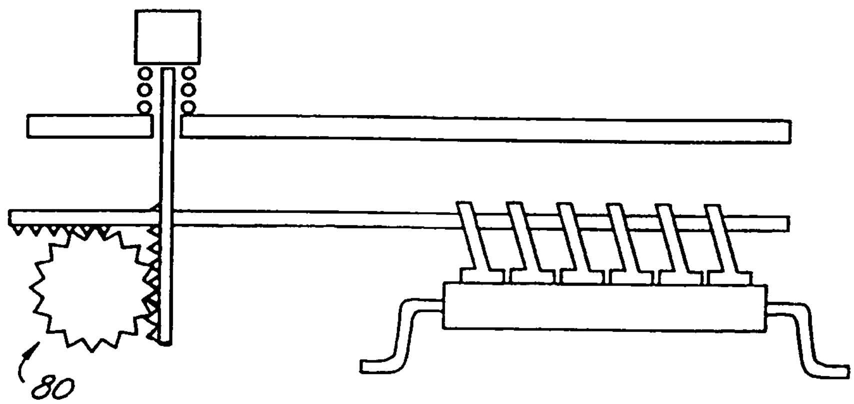

FIG.6B

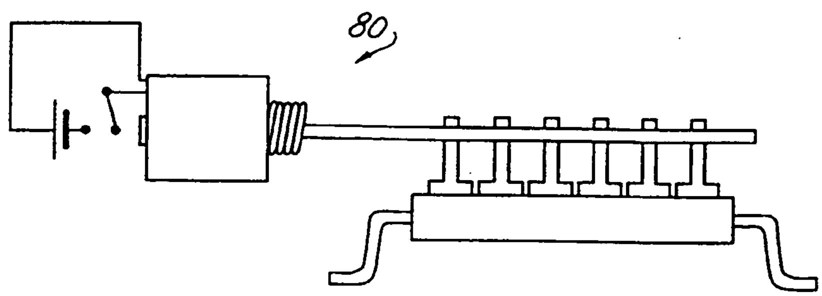

FIG.6C

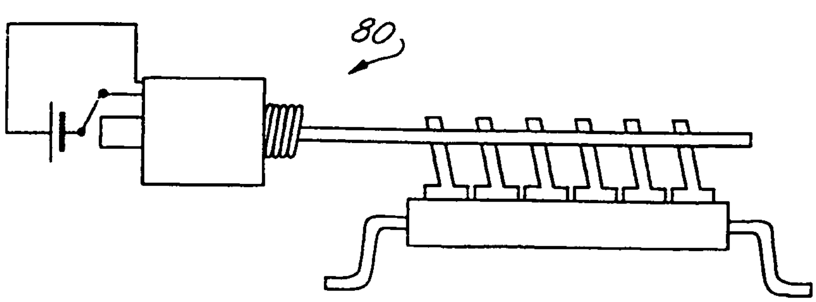

FIG.6D

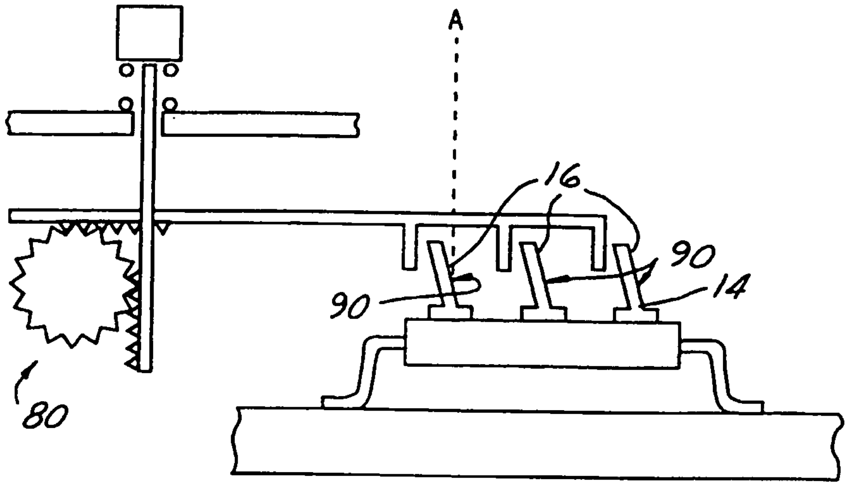

FIG.7A

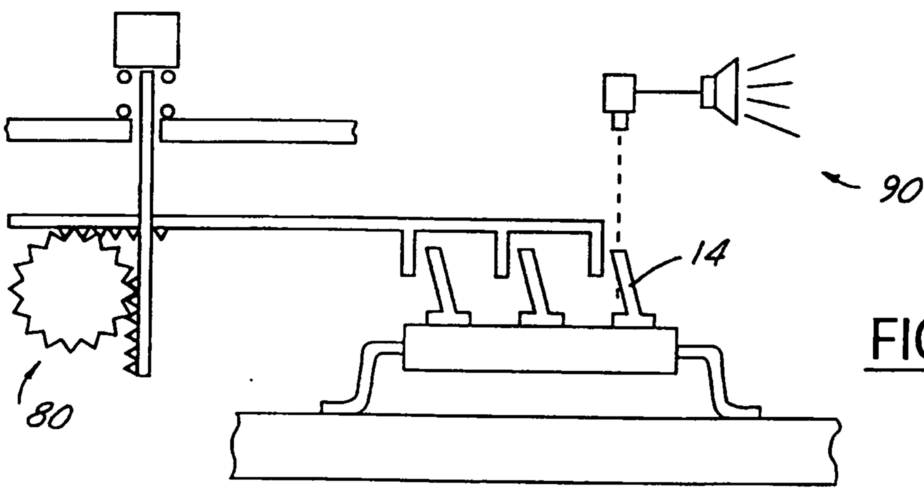

FIG.7B

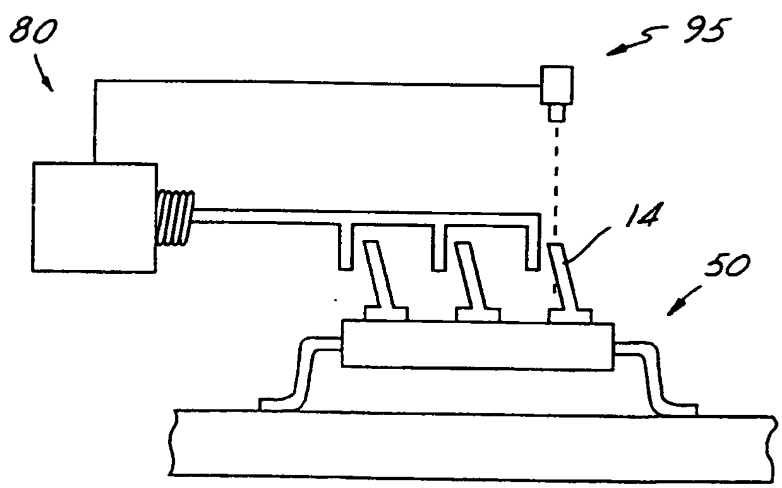

FIG.7C

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 98/02014

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01L23/373 H01L23/427

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H01L

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	PATENT ABSTRACTS OF JAPAN vol. 010, no. 273 (M-518), 17 September 1986 -& JP 61 098565 A (CANON INC), 16 May 1986,	1-6,8
Y	see abstract	7,9,10
X	PATENT ABSTRACTS OF JAPAN vol. 015, no. 233 (E-1077), 14 June 1991 -& JP 03 070162 A (MITSUBISHI ELECTRIC CORP), 26 March 1991,	1-6,8
Y	see abstract	7,9,10
X	PATENT ABSTRACTS OF JAPAN vol. 017, no. 104 (E-1328), 3 March 1993 -& JP 04 291750 A (HITACHI LTD;OTHERS: 01), 15 October 1992,	1-6,8
Y	see abstract	7,9,10

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[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
29 September 1998	12/10/1998

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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Y	US 5 483 098 A (JOINER JR BENNETT A) 9 January 1996 see figure 3	7
Y	US 4 654 092 A (MELTON KEITH N) 31 March 1987 see column 1, line 16 - column 2, line 22	9,10
A	PATENT ABSTRACTS OF JAPAN vol. 012, no. 207 (E-621), 14 June 1988 -& JP 63 006915 A (FUJI ELECTRIC CO LTD), 12 January 1988, see abstract	1-10
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